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# Development of Scroll Compressors with the High Performance used for Marine Container Refrigeration Unit

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## ABSTRACT

We have completed development of the new high performance scroll compressors by up-grading our existing air-conditioners' scroll compressors [1][2].

We have incorporated our various technologies into developing these new container's scroll compressors and have succeeded in several major achievements, including:

1) application of anti-corrosion paint, which boasts improved corrosion resistance;

2) development of a high strength casing structure, which endures 50G impact strength;

3) using the gas injection system, frozen mode [-18degree to -29degree] evaporating temperature range capacity has been boosted by a factor of 1.3.

Furthermore, we have developed test equipment that reproduces the conditions containers are subjected to and established new rating standards.

We have also increase friction part reliability by analyzing container problem trends in the field during actual operation.

## INTRODUCTION

Applications of transportation with marine container refrigeration units have expanded to include transportation of ice cream and durian (fruits) in addition to refrigeration and chilled transportation.

Under such circumstances, compressors for container refrigeration units increasingly need to be low in prices, have low maintenance and running costs and be small and compact in size, in additions to having features of high performance and high reliability.

In order to respond to the growing needs, we have developed scroll compressors for marine container units based on the scroll compressors for air-conditioners that have proven to be high in performance.

This paper describes the problems that need to be addressed when modifying compressors for air-conditioners to serve for the environment in which marine container refrigeration units are exposed and the test methods used to solve these problems. Furthermore, various technologies that were found to be useful for compressors for marine container refrigeration units through these tests are examined in this paper.

The described compressors are small-sized scroll compressors. However, with the use of gas injection system, adequate capacity can be obtained in low evaporating temperature operation. In this paper, we examined the relations between the amount of introduced gas and improved capacity.

## STRUCTURE OF COMPRESSORS

A compressor is made up of a high-pressure area and a low-pressure area. The high-pressure area is the part above the fixed scroll. The high-pressure section is separated from the low-pressure section with the fixed scroll shrinkage fit by heating onto the casing. Most of the elements including scroll, motor, crankshaft, bearing and lubricating oil is installed in the low-pressure section. A sectional drawing of the compressor structure is shown in Fig.1.

Details of the technology developed for marine container refrigeration equipment is as follows:

# DEVELOPMENTS

## a. Lubrication

### Test method

Container refrigeration equipment differs from ordinary refrigeration equipment in that the former is used under a wide range of ambient temperature conditions (conditions assumed is from –25degree to 45degree). This posed a problem in designing the lubrication. The reason is as follows: even if the ambient temperature drastically changes during operation, the oil temperature changes approximately 10degree. However, when operation is stopped, the oil temperature changes to the ambient temperature. This results in the oil viscosity changing from several cp to several hundred cp.

We assumed that the most severe condition for lubrication is when operation is started at the time when oil viscosity is the highest under low ambient temperature condition (a condition in which non-lubrication time is the longest due to delay in oil filling). Based on this assumption, we devised a test equipment (Fig.2) to identify the weakest lubrication part in this compressor. The test equipment shown in Fig.2 is unique in that it can create a condition in which oil in friction part is completely removed by condensing refrigerant from the high-pressure side when not operating, in addition to reproducing the start of operation under ambient temperature condition.

### Test results and review

Results of the preliminary tests conducted with the test equipment shown in Fig.2 revealed that the Oldham coupling where filling of oil takes place the last is the weakest. Therefore, we conducted a stop/start test for 300 times for the following three types of material. The test results are shown in Fig.3.

Aluminum alloy that proved to be effective for compressors for air-conditioners showed signs of seizure and generated abrasion. On the other hand, the two types of iron material showed good results. This is because iron material's seizure load is higher than that of aluminum under the condition of sliding speed of the Oldham coupling, as one can see from the results of the pin disk machine test under non-lubrication condition (Fig.4).

We adopted FC 250 for our commercial products because it is cost effective and is has a similar seizure resistance as nitriding SM400B that showed the best seizure resistance under the condition of sliding speed of the Oldham coupling.

## b. Anti-corrosion

### Test method

We have newly chosen anti-corrosion paint on the assumption that there is salt damage due to marine transportation. We conducted salt-water spray test (Fig.5) to evaluate the different types of paint. We also conducted a multiple-cycle test as shown in Fig.6 taking into account of container transportation. By performing the multiple-cycle test (Fig.6), we have clarified, on a test basis, the effect of environmental changes (temperature changes) to the peeling of paint film. A crosscut was made in the test piece to evaluate the paint's capacity to prevent further rusting in the case the paint is peeled because of a scratch, in addition to evaluating the resistance capability of the paint itself.

### Test results and review

Firstly, salt-water spray test was performed to select the appropriate paint. The results are shown in Fig.7. The strength of paint film was as follows:

(Weak) Powder Coating < Thick-film type of epoxy resin paint < Two-layered epoxy resin paint (Strong)

The overview of the two-layered epoxy resin paint is shown in Fig.8. The bottom layer is applied with epoxy paint containing powdered metal that has anti-corrosion action and the top layer is applied with epoxy resin containing small pieces of metal oxide that has resistance to ultraviolet ray. The ratio of thickness of paint film between top and bottom coat ranges from 1:1 to 2:1.

Next, the results of the multiple-cycle tests that were conducted to identify the relations between peeling of paint and thickness of paint film are shown in Fig.9. The results revealed that it is important to control the thickness of paint film in the ranges of 150micron to 300 micron in the case of two-layered epoxy resin paint. If the paint film was thin, rusting progressed because the film was not able to shut out the salt water. If the paint film was too thick, the film could not adjust to the expansion and shrinkage that occurred with the temperature changes during multiple-cycle test. This caused small paint cracks and peelings, resulting in further rusting.

## c. Impact strength

### Test method

Fig.10 describes the impact test based on the assumption of the impact occurring when transporting/moving containers (when loading/unloading). 50G impact strength load was put on the compressor for both vertical and horizontal directions. The impact strength was confirmed by the output from the acceleration pickup sensor. We checked for deformation of the compressor, damage to the inner components, displacement and etc. after the test. 50G is equivalent to the impact strength generated when a compressor is dropped from the height of 60cm.

### Test results and review

When this impact test was conducted with an air-conditioner’s compressor, the fixture leg was significantly deformed as is shown in Fig.11. By designing the structure of the fixture leg for container’s compressor as shown in Fig.12, we have succeeded in improving the strength of the fixture. Furthermore, the fixture is structured so that there is no stress concentration at the point where it is fixed to the casing and so that deformation of the casing can be prevented, as one can see from the results of the analysis of stress of impact (Fig.13). The impact strength is dispersed because the fixture leg is fixed onto the casing from both horizontal and vertical directions.

## d. Capacity improvements

### Test method

This compressor is designed so that intermediate pressure gas can be introduced into the middle of scroll compression room to improve refrigeration capacity at low evaporating temperature operation. We conducted tests to find out the relations between injection hole diameter and capacity improvement for this compressor.

### Test results and review

Results of the tests are shown in Fig. 14. The relations between gas injection hole diameter and improved capacity is as follows: the capacity of the compressor improved approximately in proportion to the size of the hole-diameter when the hole diameter was less than 5mm. However, if the hole-diameter is bigger than 5mm, improvements in capacity could not be observed. This shows that necessary and sufficient size of the hole-diameter is 5mm for introducing gas into the limited volume of a cylinder.

We also examined the relations between COP and injection hole diameter. We found out that if the hole-diameter is bigger than 5mm, COP dramatically decreases. This is because the injection hole becomes a leakage path within the compression room, thereby resulting in an increase in leakage loss. This compressor is designed so that the injection hole does not become a leakage path if the width of the scrolls of the compressors is less than 3.9mm.

This compressor is designed so that both capacity improvements and high COP is achieved by setting the size of injection hole diameter to 5mm.

## CONCLUSIONS

We can conclude that it is beneficial to use the following designs for scroll compressor for marine containers in order to improve its reliability in container usage.

- Use cast iron material, which has a large seizure resistance under non-lubrication conditions, for the Oldham couplings;
- Apply two layers of paint: one layer with epoxy resin paint containing metal powder and the other layer with epoxy resin paint containing small pieces of metal oxide;
- Fix the fixture leg onto the casing from both vertical and horizontal directions in order to alleviate stress concentration to the part where fixture leg and casing are welded;
- Gas injection system and its effect to capacity improvement.

## REFERENCES

[1]H.kuroiwa, et al., “Development of high-efficiency compressors with a alternative refrigerant”, 1997 international compression technique conference at Xi’an.

[2]K.matsuba, et al., Development of Highly Reliable and Efficient Scroll Compressors, Proceedings of 1998 Compressor Engineering Conference, Purdue University.

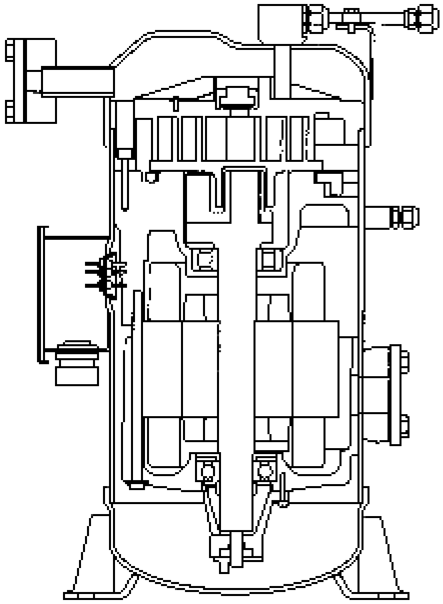
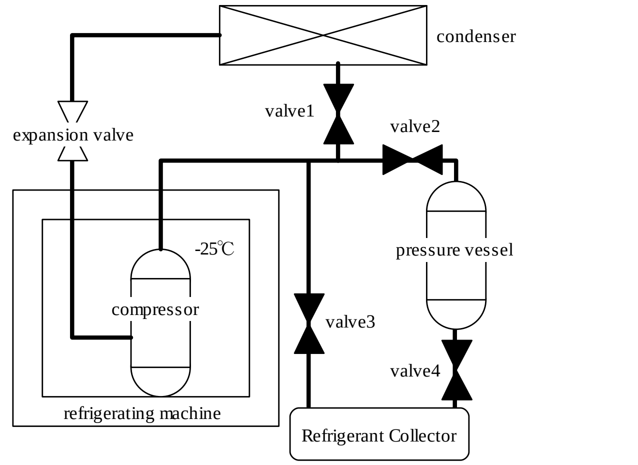


Figure 1: Sectional drawing of structure




| operation step | time | compressor | valve1 | valve2 | valve3 | valve4 | refrigerant collector |
|---|---|---|---|---|---|---|---|
| 1 | 30sec | on | open | close | close | close | off |
| 2 | 4hr. | off | open | open | close | close | off |
| 3 | 1hr. | off | open | close | open | open | on |
| 4 | 10sec | off | open | close | close | close | off |

Figure 2: Test equipment that reproduces low ambient temperature conditions

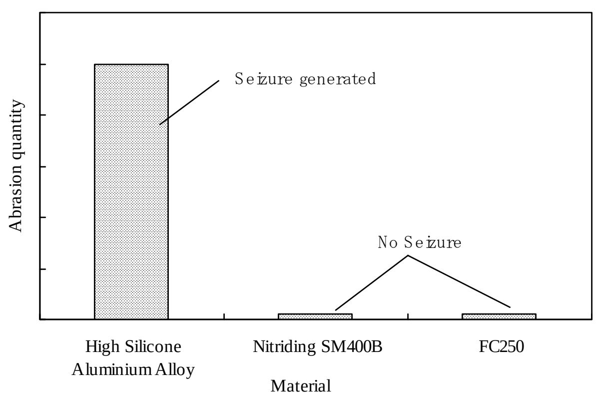



Figure 3: Test results under reproduced low ambient temperature conditions

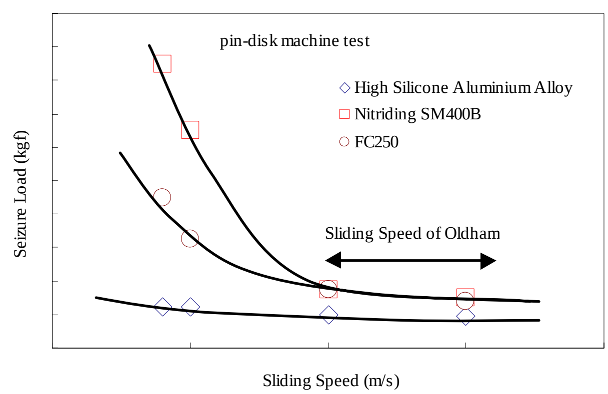



Figure 4: Seizure test result

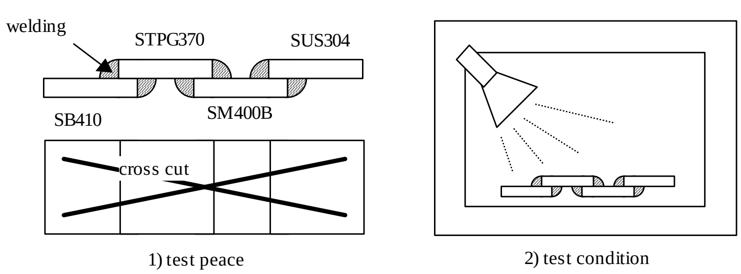



Figure 5: Salt-water spray test

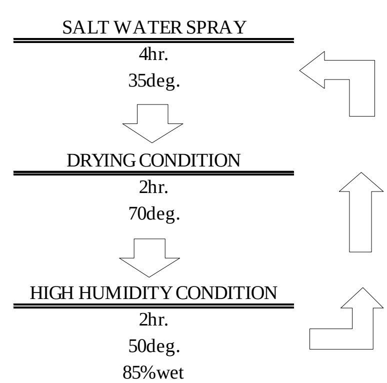



Figure 6: Multiple-cycle test

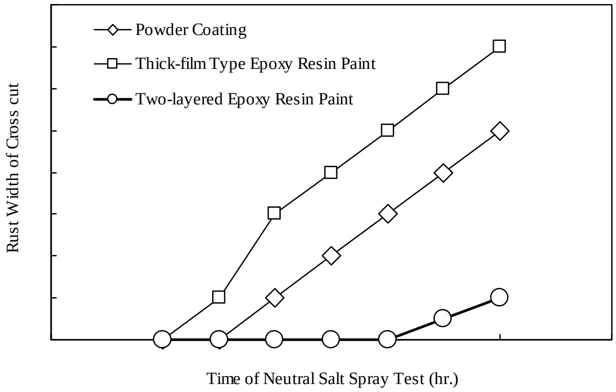



Figure 7: Result of salt-water spray test

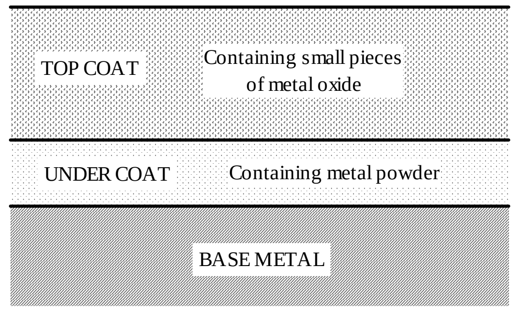



Figure 8: Overview of 2-layered epoxy resin paint

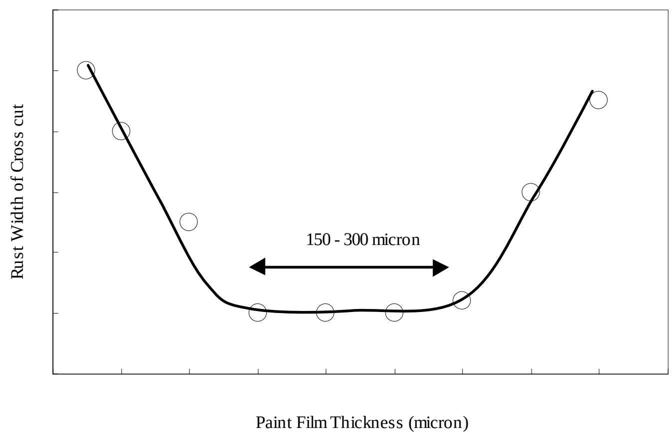



Figure 9: Result of multiple-cycle test

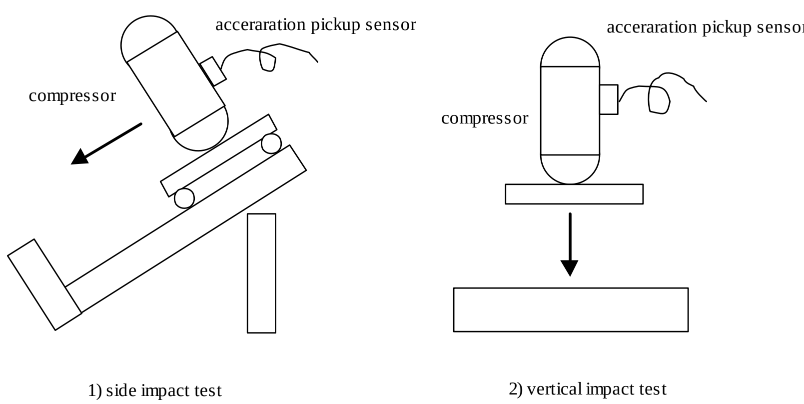



Figure 10: Impact test

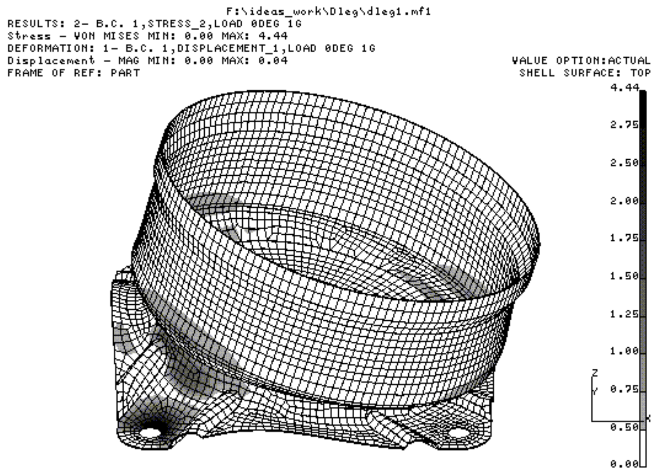



Figure 11: Deformation of fixture leg
(for air-conditioner )

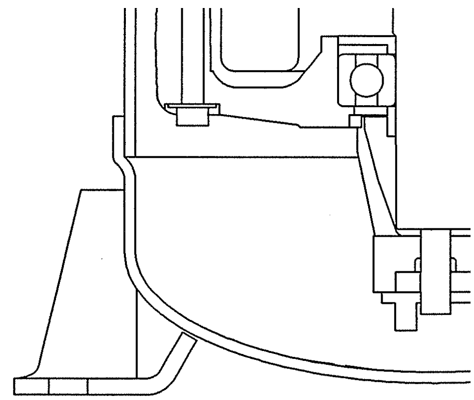


Figure 12: Structure of fixture leg
(for container)

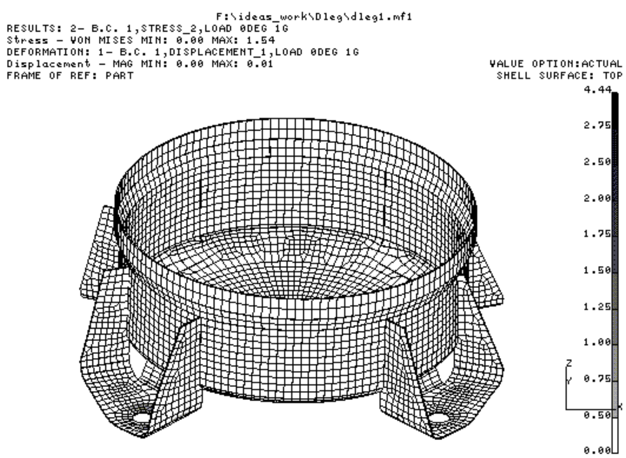



Figure 13: Deformation of fixture leg
(For container)

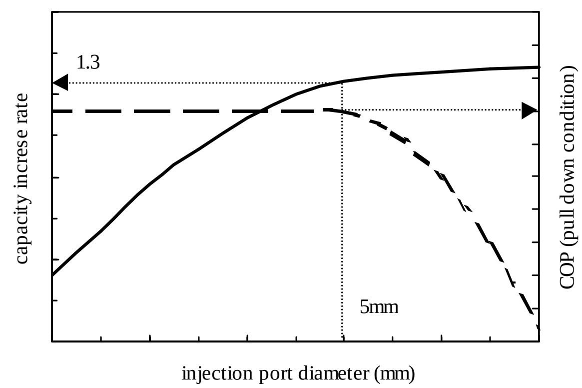



Figure 14: Relations between gas injection hole-
diameter and capacity improvement